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b-Physics at CDF and Prospects for the Next Run

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Abstract

Current CDF b-physics results are presented. The analysis is based on data corresponding to an integrated luminosity of 4.4 pb^{-1} recorded with the CDF detector in 88-89 at the Fermilab Tevatron $p\overline{p}$ collider ($\sqrt{s} = 1.8$ TeV). Preliminary results include the differential cross section $\frac{d\sigma(b)}{dP_t}$, some reconstructed exclusive B-decays, a limit for the rare decay $B^0 \to \mu^+\mu^-$ and a measurement of $B\overline{B}$- mixing parameters. Finally we will discuss the prospects concerning b-physics for the next data run which will start in February 1992.

1 Introduction

The CDF detector for the Fermilab Tevatron $p\overline{p}$ collider ($\sqrt{s} = 1.8$ TeV) combines good tracking ($\frac{\delta P_t}{P_t^2} \simeq 0.002$ $(\mathrm{GeV/c})^{-1}$) with calorimetry which gives it good lepton identification capabilities. A detailed description of the detector can be found in reference [1]. The detector and its triggers are optimized for high P_t physics to maximize the signal from W's, Z's and top quarks and so it is in principle not well suited to do b physics. Fortunately nature provides us with a very high $b\overline{b}$ production cross section at the Tevatron. So that, although we can access only high P_t central b's decaying into a lepton + x or a J/ψ + x, it is possible to do a lot of interesting b-physics with the CDF detector.

2 The b-quark production cross section $\frac{d\sigma(b)}{dP_t}$

The cross section for b-quarks with a $P_t > 15$ GeV was measured [2] using the inclusive electron sample which consists of 0.2 pb^{-1} collected with a 7 GeV trigger threshold and 4.4pb^{-1} collected with a 12 GeV threshold.

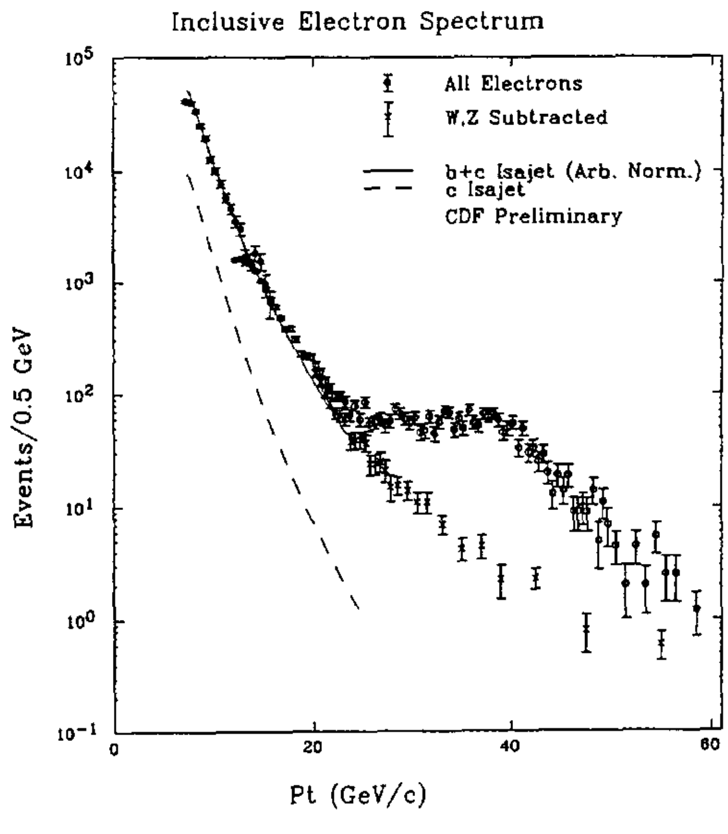

Figure 1: *Inclusive Electron Spectrum for* $|\eta| < 1$.

Figure 1 shows the observed electron P_t spectrum for the central pseudorapidity region $|\eta| < 1.$, before and after W and Z subtraction. The solid line shows the prediction of the ISAJET Monte Carlo normalized to the experimental data. ISAJET reproduces the P_t spectrum as calculated by Nason, Dawson and Ellis [3]. The dashed line shows the contribution from charm decays as predicted by ISAJET. According to ISAJET 90 % of the electrons in our data sample are from semileptonic b-decays with a 10 % background from charm-decays.

The shape of the distribution agrees very well with the theoretical prediction.

To check if these electrons are really coming from semileptonic b-decay we searched for associated charm within a cone of $\sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.6$ around the electron direction. We observe a clear $D^0 \to K\pi$ peak (Fig. 2).

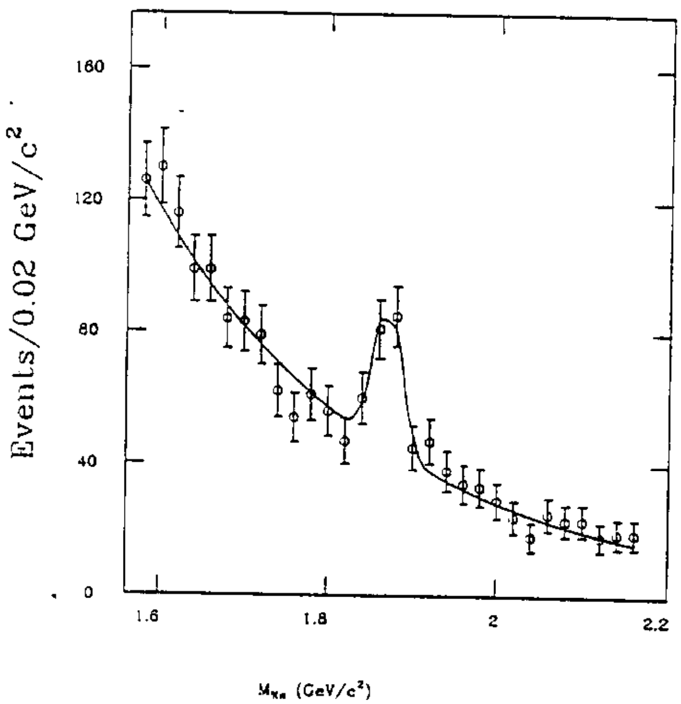

Figure 2: *Invariant Mass Spectrum of K π pairs for hadron tracks near a high* P_t *electron.*

Furthermore we checked the invariant mass spectrum of the e-D^0-system. The spectrum peaks below the mass of the B-meson as expected because of the missing momentum carried by the neutrino. This proves that we are not dealing with charm pair production close in phase space where one charm particle decays semileptonically

From the electron P_t spectrum we derived the b-quark cross section as a function of P_t. In Figure 3 the result is compared with the theoretical prediction [3].

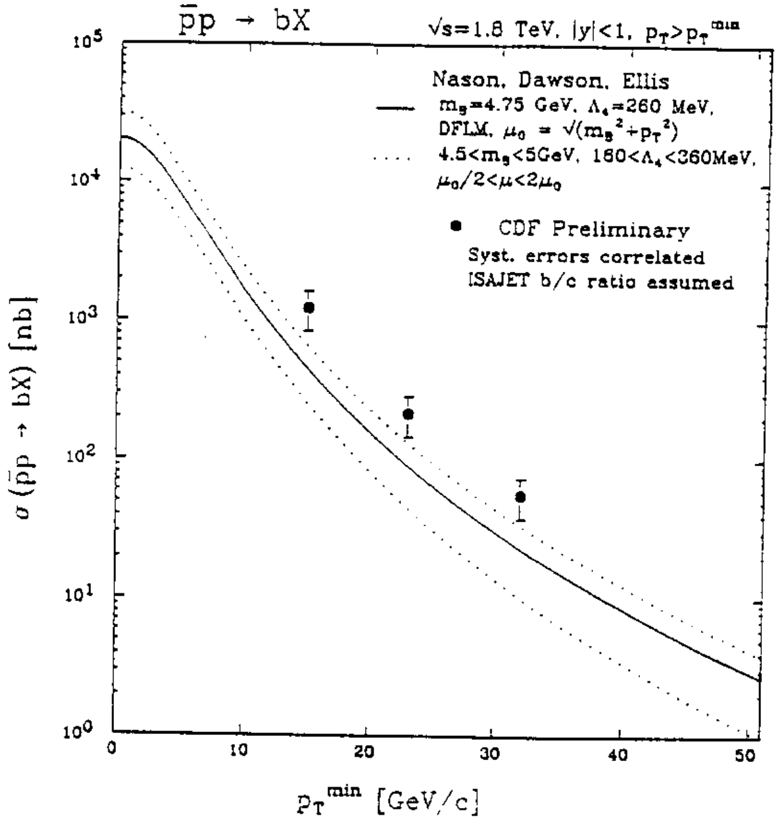

Figure 3: *b-quark cross section as a function of b-quark* P_t.

3 Reconstruction of exclusive decays.

To reconstruct exclusive B-decays we used the $J/\psi \to \mu^+\mu^-$ data sample [4]. As shown in Figure 4 we observe a very clean J/ψ peak over a small background. The width of the gaussian distribution fitted to the data is consistent with the excellent momentum resolution of the central driftchamber.

The J/ψ data was mainly collected using the central dimuon trigger. This trigger required two muon candidates with a $P_t > 3$ GeV within the acceptance of the

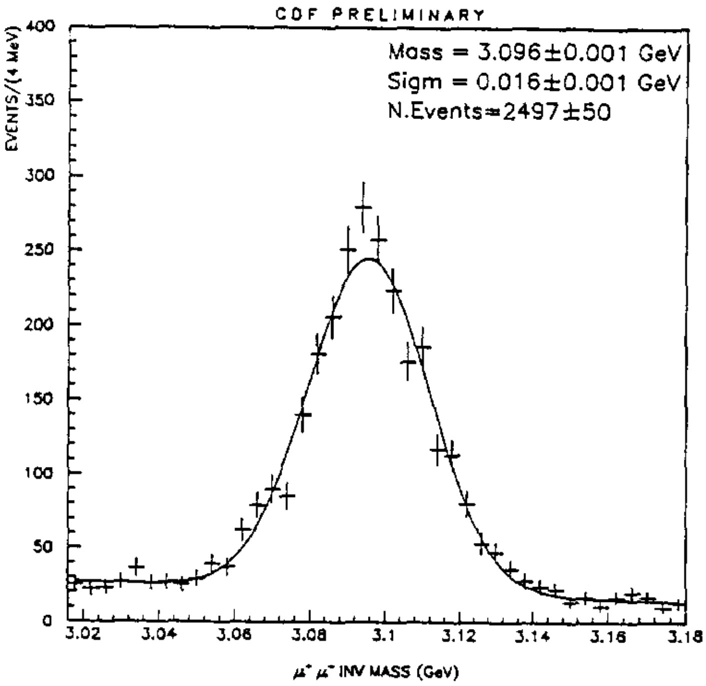

Figure 4: $J/\psi \rightarrow \mu^+\mu^-$ *sample.*

cept only very central high P_t J/ψ's. Their mean P_t is 8 GeV. It is expected [5] that a large fraction of these J/ψ's comes from B-decays.

If the J/ψ's come from B-decay the mean P_t of the parent B-meson is about 12 GeV and its decay products are boosted into its direction which is approximately the J/ψ direction. Furthermore the J/ψ's are heavy so that a large fraction of all the decays including a J/ψ are 2 and 3 body decays.

We reconstructed the two decays: $B^\pm \rightarrow J/\psi\, K^\pm$ and $B^0 \rightarrow J/\psi\, K^{0*} \rightarrow J/\psi\, K\,\pi$.

The first step of reconstruction is in both cases the same: we find the $J/\psi \rightarrow \mu^+\mu^-$ and do a mass constrained fit of the J/ψ tracks to improve the mass resolution for the B-meson. Then for the decay $B^\pm \rightarrow J/\psi\, K^\pm$ we beam constrain all other tracks assuming that these are kaons and select all tracks with a $P_t > 2.5$ GeV which are within a cone of 60^0 around the J/ψ. Finally we calculate the invariant mass of the J/ψ K pair.

For the $B^0 \rightarrow J/\psi\, K^{0*} \rightarrow J/\psi\, K\,\pi$ we select the 3 highest momentum tracks within a cone of 60^0 around the J/ψ, then we form opposite signed track pairs using both possible assignments of K and π mass and accept only K π pairs where the invariant mass is within 50 MeV of the K^{0*} mass. Figure 5 shows the invariant mass spectrum for both decay modes combined. The fit superimposed to the spectrum gives 5279 MeV for the B-mass. The total number of events is 35 ± 9.

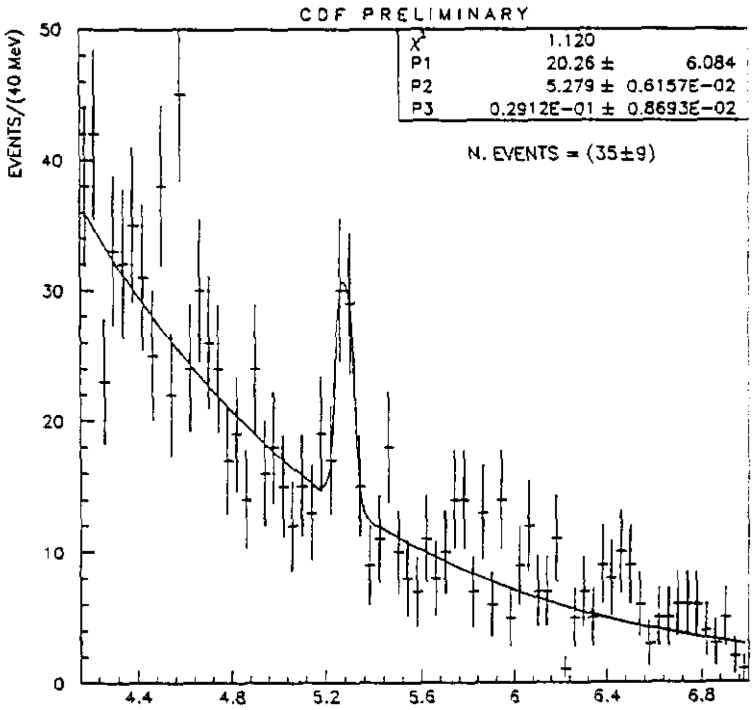

Figure 5: *Invariant Mass Spectrum* ($B^0 \rightarrow J/\psi\, K^{*0}$ *and* $B^\pm \rightarrow J/\psi\, K^\pm$ *combined).*

4 A limit for the rare decay $B^0 \rightarrow \mu^+\mu^-$

We searched for the rare decay $B^0 \rightarrow \mu^+\mu^-$ [6], which is a flavor changing neutral current decay allowed by the standard model at very low rate. The expected branching ratio is [7]: $BR(B^0 \rightarrow \mu^+\mu^-) \simeq 10^{-8}$ to 10^{-9}.

To derive a limit for the branching ratio, we compare this decay with the decay $B \rightarrow \psi' X \rightarrow \mu^+\mu^- X$. We assume that all the ψ''s are from B decay and that 50% of them are from neutral and 50% are from charged B mesons. The branching ratio $BR(B \to \psi' x \to \mu^+\mu^- X)$ is $2.5 \pm 1.2 \cdot 10^{-5}$. By measuring the rate ratio of the two decays we find that systematic uncertainties in trigger efficiency, b-production properties, luminosity etc., cancel. The acceptance ratio ϵ_{acc} was calculated using Monte Carlo's to be:

$$\epsilon_{acc} = \frac{A(B \to \psi' x \to \mu^+\mu^- x)}{A(B^0 \to \mu^+\mu^-)} \simeq \frac{1}{4}$$

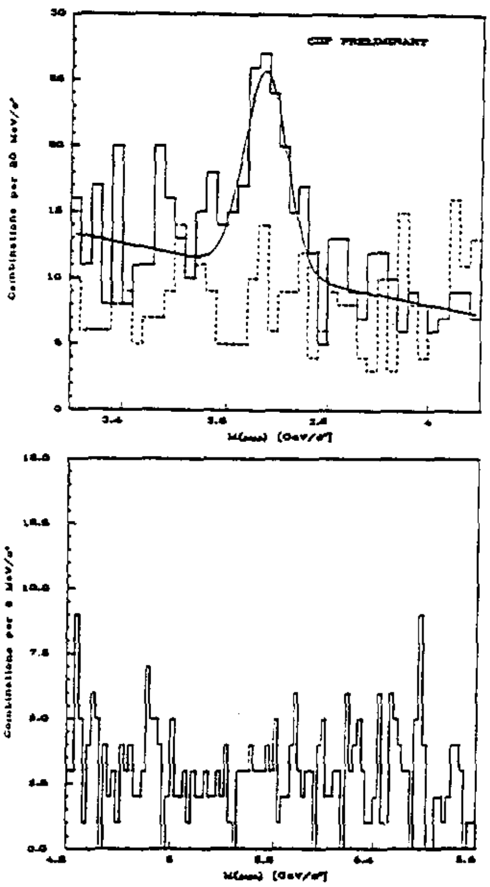

Figure 6: *$\mu^+\mu^-$-Invariant Mass Spectrum in the a.) ψ' and b.) in the B-meson mass region.*

Figure 6 b.) demonstrates that the invariant mass distribution in the B^0-mass region is consistent with a flat background. The fit gives an upper limit of 12 events at 90% confidence level compared with 72 ± 17 events in the ψ'-mass region. So we obtain the following ratio of the rates:

$$\frac{N(B^0 \to \mu^+\mu^-)}{N(B \to \psi' x \to \mu^+\mu^- x) \cdot 0.5} \cdot \epsilon_{acc} =$$

$$\frac{12}{(72 \pm 17) \cdot 0.5} \cdot 0.25$$

This gives: $BR(B^0 \to \mu^+\mu^-) < 3.2 \cdot 10^{-6}$ at 90 % Confidence Level. This is the most stringent existing limit. The UA1-collaboration quotes: $BR(B^0 \to \mu^+\mu^-) < 8.3 \cdot 10^{-6}$ in [8]. In the Particle Data Book [9] we find $BR(B^0 \to \mu^+\mu^- < 5 \cdot 10^{-5})$.

5 Measurement of $B^0\overline{B}^0$ Mixing using e μ-events

$B^0\overline{B}^0$ mixing is a second order weak interaction effect which originates from the box diagrams shown in Fig. 7. It depends on the B-meson lifetime, the elements of the CKM matrix and the masses of the b and top quarks. So measuring mixing parameters gives access to parameters of the Standard Model and allows to check its validity. Mixing has been studied at e^+e^--machines and at the $Sp\overline{p}S$ Collider [10].

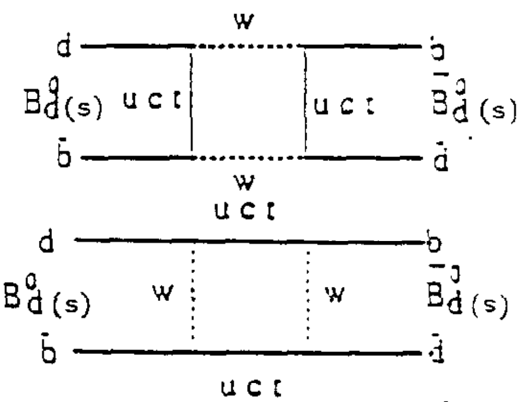

Figure 7: *Box diagrams for* $B^0\overline{B}^0$ *Mixing.*

When using events where both b's in a $b\overline{b}$-event decay semileptonically the charge of the leptons tags the flavor of the b-quark. Mixing is a source of like sign (LS) lepton pairs. The mixing parameter χ gives the probability of $B^0\overline{B}^0$ mixing in $b\overline{b}$-events, where B^0 refers to B^0_d or B^0_s. So this parameter is the average of the B^0_d and B^0_s mixing parameters χ_d and χ_s

$$\overline{\chi} = P_d\chi_d + P_s\chi_s$$

where

$$P_{d(s)} = \text{Prob}(b \rightarrow \overline{B}^0_{d(s)})\frac{BR(\overline{B}^0_{d(s)} \rightarrow l^-X)}{BR(b \rightarrow \overline{B} \rightarrow l^-X)}$$

$\overline{\chi}$ is related to the ratio R between LS and opposite sign (OS) lepton pairs in the following way:

$$R = \frac{N(LS)}{N(OS)} = \frac{2\overline{\chi}(1-\overline{\chi}) + [(1-\overline{\chi})^2 + \overline{\chi}^2]f_s}{[(1-\overline{\chi})^2 + \overline{\chi}^2] + 2\overline{\chi}(1-\overline{\chi})f_s + f_c}$$

where

f_s : Probability of sequential decay $b \rightarrow cX \rightarrow lX$

f_c : Probability of OS dileptons from $c\overline{c}$

Using e μ-events has the advantage that the rate is high (twice: ee, $\mu\mu$) and that there is no background from DY, J/ψ, Υ.

After applying CDF standard cuts for electrons and muons the sample consists of 429 LS and 911 OS eμ-events [11]. The P_t threshold is 5 GeV for the electrons and 3 GeV for the muons. Figure 8 shows the invariant mass distribution for LS and OS lepton pairs.

To remove sequential b decays ($b \rightarrow clX \rightarrow llX$) we require that the invariant mass of the eμ-pair is greater than 5 GeV. This cut also preferentially removes pairs with a small relative angle. After this cut we have 346 LS and 554 OS events.

The fake leptons background comes mainly from fake muons. The rate of fake muons has been estimated using other CDF data samples. They contribute equally to LS and OS pairs. So we get the following value for R:

$$R = \frac{346-90}{554-90} = 0.552 \pm 0.049(\text{stat}) \pm^{0.039}_{0.048}(\text{bkg}).$$

The ISAJET Monte Carlo gives:

$f_c = 0.066 \pm 0.066$ and $f_s = 0.248 \pm 0.055$.

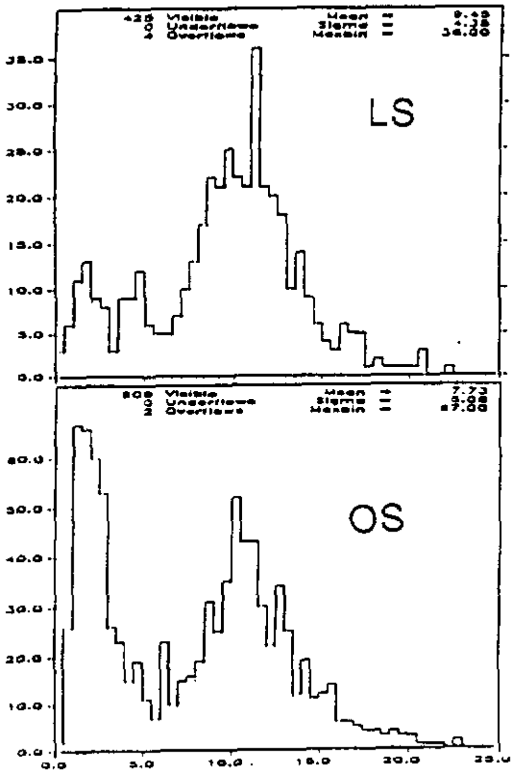

Figure 8: *Invariant Mass Distribution for LS and OS lepton pairs.*

Finally we obtain the following value for $\overline{\chi}$:

$\overline{\chi} = 0.176 \pm 0.028(\text{stat}) \pm 0.025(\text{bkg}) \pm 0.032(\text{MC})$

Within the errors this is in good agreement with the UA1 results: $\overline{\chi} = 0.148 \pm 0.029(\text{stat}) \pm 0.017(\text{sys})$

6 Prospects for the next run

Analyzing the 88/89 data CDF demonstrated its ability to do b-physics at a hadron collider. The next data run which consist of two parts is expected to start February 92. The first part of the run will last about 6 months and the goal is to record 25 - 30 pb^{-1} on tape during that time. This is about 6 times the luminosity integrated in 88/89. For the second part the goal is more than 50pb^{-1}.

The upgraded CDF-detector will be equipped with a microstrip Silicon Vertex Detector (SVX) (for a description see reference [12]). This device will have an impact parameter resolution of about 10 μm for tracks with a transverse momentum of more than 1 GeV.

In addition, the central CDF muon system will be improved. The muon acceptance which is used in the trigger will be increased by roughly a factor of two and the shielding in the central part ($|\eta| < 0.7$) will be increased so that the background from hadron punch through will be suppressed by a factor of five. Both improvements will allow us to lower the trigger thresholds: e.g. in the 88/89 run the central dimuon trigger required both muon candidates to have a P_t of 3 GeV, in the next run this threshold will be 1.8 GeV. For the dimuons we are expecting an overall increase of trigger efficiency by a factor of 16. We expect to fully reconstruct more than 3000 B's in the $B \rightarrow J/\psi + X$ channel in 25 pb^{-1}.

This data sample will be a good starting point to do b-spectroscopy and we hope to discover the not yet found higher mass states of the b-quark in the following channels: $B_s \rightarrow J/\psi\, \varphi \rightarrow J/\psi\, K\, K$, $\Lambda_b \rightarrow J/\psi\, \Lambda \rightarrow J/\psi\, p\, \pi$ $B_c \rightarrow J/\psi\, \pi \ldots$
With the SVX it will be possible to reduce the combinatorial background significantly by assigning the B-decay candidate tracks to a common vertex and to measure the lifetimes of the different B hadrons (B^0, $B^\pm$, B_s, Λ_b) separately. Of particular interest will be the reconstruction of the decay $B^0 \rightarrow J/\psi\, K^0_S$ where the final state is a CP-eigenstate and a promising candidate for the future measurement of CP-violation in the $B\overline{B}$ system.

Besides improving our limit for the decay $B^0 \rightarrow \mu^+\mu^-$ we will search for the so called 'Penguin'-decay $b \rightarrow s\mu\mu$.

Also the single muon and single electron triggers will be improved in the next run. We expect 30000 leptons from b-decay per pb^{-1} for each of these triggers. Depending on the performance of the SVX it will be possible to make an unbiased study of the second b in the event.

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